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An Assessment of the Financial Viability of Small-scale Commercial Aquaponic Systems in Barbados

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ABSTRACT

The aquaponics technology has grown in interest over the years. Within Barbados, persons are opting to use this system for growing their crops and also offer those crops for sale. Aquaponics incorporates both hydroponics and aquaculture where crops and aquatic species are grown in a recirculating system without the use of soil. This farming technique has been considered in various literature as sustainable and efficient in the use of resources.

Although it is promoted as a technique by which farmers can earn an income, it is unclear as to whether this form of production is financially viable despite the positive environmental aspects. This paper, therefore, assesses whether or not aquaponics production in Barbados is financially viable and whether it should be promoted to farmers in the country. To determine the viability, two existing aquaponic farms were studied and were compared and contrasted to the other. The start-up and operational costs were identified as the financial costs. The benefits were the revenue gained from selling the fish and the crops. Both the financial benefits and costs identified for the two farms were analysed using the benefit cost analysis and based on the results from the benefit cost analysis, both aquaponic systems were found to be viable within a Barbados context.

1. Introduction

Aquaponics is an integrated system that incorporates both hydroponics and aquaculture. It is a recirculating system that combines the production of plants and aquatic species without the use of soil. This type of technology, according to Goddek et al. (2015), is a promising sustainable food production method that has been considered as an innovative response for food security. With the earth's population expected to reach 9.8 billion by 2050 (UN, 2017), there will be an increased demand on natural resources. To meet the demand of the growing population, food production will need to increase which will in turn require improved resource use efficiency. It is expected that the demand for food production would lead to the decrease in arable land, constrained water resources and soil degradation (Goddek et al. 2015).

Taking into account the pressure that will be expected and exerted on the natural resources, especially those required for food production, aquaponics could be a sustainable alternative in farming. This kind of technology would improve the way farmers produce their crops while providing beneficial financial gains to the farmer with reduced negative impact on the environment.

Some of the positive environmental impacts of aquaponics include the recycling of the nutrients as the nutrient rich water is not disposed as well as the low water use requirement, which reduces the pressure on water to supply food. This type of system is relevant for Barbados due to the water challenges the island faces such as water scarcity.

Within Barbados, the interest in aquaponics has grown over the years as persons seek new and economic ways to grow food while still gaining an income. With aquaponics two profit making items i.e. the fish and plants can be sold and at the same time be profitable to the farmer. Although the interest in aquaponics is growing, the number of aquaponic owners within

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Barbados is still quite small; there are about 10 to 20 persons which use aquaponics as a backyard set up (FAO 2017).

Therefore, it was only fitting then that information is provided to farmers on the financial viability of aquaponics and the benefits that it provides within the Barbados context.

Previous studies on aquaponics have provided information on the financial and economic feasibility of aquaponics. However, according to Goddek et al. (2015), there are limited data on the cost and the profits that can be gained through aquaponic systems. Additionally, there are limited data on actual aquaponic systems in Barbados being evaluated to determine the viability for the Barbados context.

To explore the financial viability of aquaponics within Barbados, a benefit cost analysis was used. Financial viability in this context looks at the ability of a particular enterprise to generate sufficient income to meet operating payments, debt commitments and in the process allow growth (NSW 2018).

Providing farmers the knowledge needed on the financial prospects of this technology would encourage more farmers to use aquaponics for growing their crops and provide them with a better understanding on the financial viability to make informed decisions when it comes to using the aquaponic systems.

With proof to show that aquaponics is financially viable, it can create more employment opportunities. According to Oosthizen 1998, provision of employment opportunities can have spill-over effects to the economy, "such benefits would be felt throughout the economy and would be in favour of lower-income groups" (Oosthizen 1998). Introducing this new and innovative production technology can be a powerful force for economic development.

1.1. Research aims and objectives

Therefore, the aim of this study is to assess the financial viability of setting up and operating small-scale commercial aquaponic systems in Barbados. The main objectives were:

To provide an overview of an aquaponics system and how it operates;
To study the operation of two small scale aquaponics farms from set up and operation over a period of two months; and
To identify the benefits and costs of setting up and operating an aquaponics farm

1.2. Overview of aquaponics

Generally, aquaponic systems mimic the recirculating aquaculture system where water (effluent) from the fish rearing tank is cycled through filters, the plant beds and then back to the fish. Within aquaponics the water is not released to the environment but is kept in a closed loop. The water from the fish rearing tank is sent through a solid separator where the mechanical filtering occurs removing the large suspended and settable solids. Thereafter, the water passes through the biofilters or the plant growing bed to remove the ammonia and the nitrate. Within the biofilter, beneficial bacteria are located on the sides of the tanks and on the sides of the plastic material (e.g. polystyrene) to break down ammonia to nitrate which the plants will use to grow. Once the water passes from the biofilter, it goes to the plant growing bed where the plant roots which reaches the water takes up the nutrients.

After passing the plant growing bed, the water collects in the sump (reservoir) tank and is pumped back to the fish rearing tank. Through this recirculating system, it allows for the fish, plants and bacteria to thrive symbiotically while providing a healthy growing environment for each of the three groups of organisms (FAO 2014). The physical setup of an aquaponic system varies and is dependent on factors such as available space and other physical characteristics.

There are three different types of aquaponic systems; these are the nutrient film technique, the deep water culture or floating raft and the media bed system. The nutrient film technique uses horizontal pipes which contains holes for the plants. This system allows for a shallow stream of water to pass through the pipes where the plant roots can reach the water. The deep water culture is different in that the plants are suspended in perforated polystyrene sheets that float on the surface of the water and the plant roots hang down into the water. The media bed on the other hand, uses medium such as gravel, expanded clay or perlite to provide support for the plant roots and at the same time also act as a filter.

1.3. Financial cost and gains from aquaponics

According to the literature, aquaponics have been found to be very costly during the start-up of the system. They require a large capital investment, moderate energy inputs and skilled management along with having a niche market that can provide the profitability (Rakocy et al. 2006). However, when aquaponics is compared with conventional agriculture, the key costs associated with aquaponics such as nutrients, land and water are reduced significantly (Blidariu and Grozea 2011).

Some of the costs expected in aquaponics are fixed costs and variable costs. Fixed costs such as the capital items do not change with output but are only replaced after they reached their expected lifespan. Fixed costs included infrastructure, insurance and permitting (Bunyaviroch et al. 2013). Other items included as fixed costs, were capital items such as land, office equipment and backup generator according to Adler et al. (2000). In other studies, the fixed cost for aquaponic systems were the materials such as polyvinyl chloride (PVC) pipes and fittings, valves, pumps, tanks, growing media, pots etc. (Petrea et al. 2016) and these items are required for the first physical set up of the system.

The operational costs are those costs, which recur every year and these were the costs related to the day to day activities in maintaining and running the aquaponic system. In one study conducted in the United States of America, about 60% of the annual operational costs was made up of the employee salaries and energy cost. It was found that if the aquaponic system had a greenhouse component, it brought the cost to about 63% of the aquaponic system. As such, a system like this would require a large amount of labour (Adler et al. 2000). Depending on the hourly labour rates, labour costs can be considerably high. Therefore, aquaponics work best when the vegetables are expensive and the labour is cheap. Other operating costs included the utilities (water and electricity), chemical supplements and transportation. The largest operating cost in the study conducted by Bunyaviroch et al. (2013) was the cost of electricity which accounted for 41% of the total yearly expenses.

In other studies, the largest operating cost was the salary (Bosma et al. 2017). When the fish rearing component is taken into account, the costs associated with this aspect of operation included the fish feed and the replacement of the fish. In a study conducted by Bunyaviroch et al. 2013, the cost of the replacement/replenishment fish was found to be costly. According to (Hambrey Consulting 2013) the fish rearing component of aquaponics can increase the capital and operating costs when compared to hydroponics. In terms of the crops, the costs associated with the crop component is the cost of the seedlings to replace the harvested crops. The production of the crops tend to bring in most of the revenue and according to Adler et al. (2000) the crop component can bring in about 67% of the annual revenue.

In order "to recover the high capital cost and operating expenses of aquaponic systems, according to Rakocy et al. (2006) the aquaponics system must still earn a profit and both the fish rearing and the hydroponic vegetable components must operate continuously near maximum production capacity". To gain a profit, the farmer must have a market for which to sell the crops and the fish. As recommended by Hambrey Consulting 2013, premium niche markets would be required and the demand must be appropriate for the quantity of fish and vegetables produced in order to be profitable.

Based on the previous studies conducted on aquaponics, they have shown to be viable in some instances, however, profitability is dependent on the type of crops grown, the size of the market and the ability to expand to new markets and locations (Bunyaviroch et al. 2013). An important factor to consider is the payback period, as this determines the length of time the system would recover the initial fixed costs (Adler et al. 2000). As outlined by Bregnballe (2015), the payback can take about two years, and this is starting from the construction of the system to the selling of the first set of fish.

2. Methodology

2.1. Study area

Two study sites were selected based on the availability of the farmers that operated aquaponic systems within Barbados. Although there is a growing interest in aquaponics within Barbados there were still only a few farmers/persons which used aquaponics. Farm A was located in St. James and Farm B in St. Thomas. The primary data from both these farms were obtained through semi structured interviews.

2.2. Data collection

Desk research was conducted to obtain information on aquaponic system operations, financial assessments and other relevant information. Before any primary data collection was done, initial site visits were conducted to gather information about how each farms' aquaponic system worked. Following the discussions with the owners, a questionnaire was developed for conducting the semi-structured interview with the owners to understand more about the operation of the aquaponic system and the necessary materials required for starting and operating the aquaponics.

Weekly visits were conducted on one farm by the author in order to collect data on the volume of water used, electricity usage and crop sales. On the first week, the visit sought to obtain the size of the growing area, the sump tanks, fish tanks and the filter tanks in order to obtain the volume of water required for the initial filling up of the system. For Farm B the owner opted to collect the data required for the study and provide it to the author. For the two farms, the data collection was done over a period of two months (8 weeks) starting from August to September 2018 for Farm A and for Farm B; the data was collected from September to October 2018.

Information relating to the start-up capital and operational cost and the sale price of the crops and fish were obtained from the owners and these have been quoted in Barbados dollars (BBD). Local businesses were also contacted to obtain cost estimates for items such as materials for constructing aquaponics, seedlings, fish feed and any other costs which the farmer could not provide.

In terms of assessing the financial viability of aquaponics, from start-up and to operation, the Benefit Cost Analysis was used. The benefit cost ratio (BCR) obtained was used to determine if aquaponics is financially viable. The costs and the revenue (benefits) were placed into tables along with the present value of the costs and the benefits which were calculated using a discount rate of 8% obtained from the World Bank collection of development indicators. The net present value was calculated using the net present value formula from excel. The net present value obtained for each year was calculated over 5 years based on the assumption that no new equipment or materials were required during that period.

Graphs were used to display the percentage break down of the operation cost and tables were used to display the benefit cost analysis for 5 years and the operational costs.

2.3. Limitations

The revenue data for the two farms were not provided by the owners therefore, the revenue that would be earned through the crops had to be estimated based on the number of crops grown. The total revenue from the vegetables were determined based on sale prices provided by the farm owners. It was also assumed that 10% of the total crops would be lost due to pests. Additionally, the cost of acquiring land was not included in the start-up cost; it was assumed that the farmer already had land. Other costs that were not included, were delivery, packaging and taxes etc. The exclusion of these costs may affect the financial viability and the total costs involved in aquaponics.

Another limitation was in reading the water meter for Farm A as the meter could not be read due to some unforeseen circumstances and as such the changes in the initial and final volume of the sump tanks, fish tanks, and biological and mechanical filter tanks each week had to be calculated from onsite measurements. This was done from measuring the change in volume of the water in the system over a period of a week.

3. Results

3.1. Aquaponics design of the study sites

The design of both aquaponic systems were different, with Farm A's system design consisting solely of the nutrient film technique (NFT) system and Farm B consisted of a combination of two different types of systems these being the deep water raft and NFT (which was set up into an A frame). Both farms were supplied with water from the Barbados Water Authority. Farm A's aquaponic farm and the household were connected to the same water meter. The system was set up with a three thousand two hundred and two (3,202) hole capacity for growing the crops. While the aquaponic system for Farm B consisted of a thousand (1,000) hole capacity for growing the crops. The aquaponic farm was an addition to the fish farming operation that the company has and both were connected to the same water meter. The aquaponic system was also set up as a demonstration site under the funding from the Food and Agriculture Organization of the United Nations.

The flow of water through both Farm A and B followed a similar pattern with slight variations. The flow of water in Farm A's system was as follows, the water flowed into the sump (sump contained the water pump) from the sump the water flowed to the plants then from the plants back to the sump. Some of the water flowed to the fish and back to the plants. From the fish tank the water flowed to the solid separator (mechanical filter) then to the biofilter and then to the sump and this cycle continued. Figure 1 is a schematic of the farm.

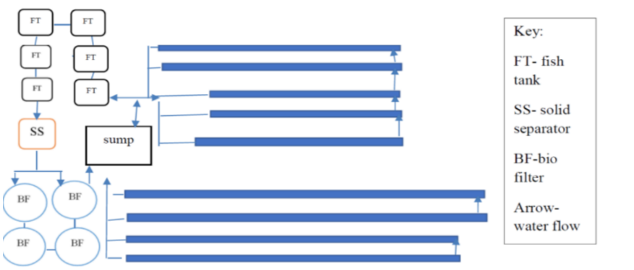

Fig. 1 - Schematic of Farm A's aquaponic system.

For Farm B the water flowed from the sump which consisted of two sumps, sump 1 and sump 2. From the sump, water flowed to the fish tank and to the deep water raft. From the deep water raft, water flowed back to sump 1. For sump 2 water flowed from the sump to the A frame and from the A frame back to sump 2. Water which goes to the fish tanks goes to the mechanical filter then to the sump. This system had a small bio filter since the plants acted as a biofilter. Figure 2 is a schematic of the farm.

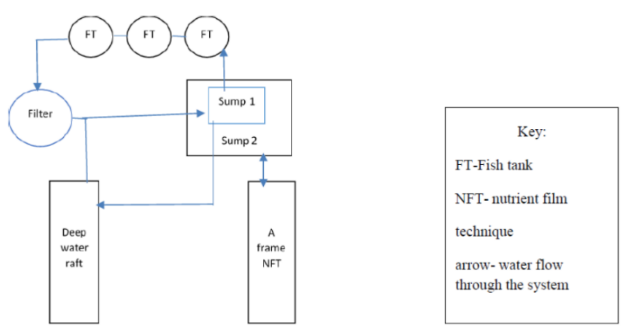

Fig. 2 - Schematic of Farm B's aquaponic system.

Based on the system set up and the size of both aquaponic systems the water that would be required for the initial fill up would be 8 cubic metres (m3) for Farm A and for Farm B 15 cubic metres. After the initial filling of the system, the water used by aquaponics would be to top up the system when water is lost through evaporation, transpiration or spillage. The weekly water used for both systems ranged from 0-1.6 m3.

3.2. Start up and Operational Cost

The costs obtained from the two farms over the 8 weeks were compiled to represent one month of the operational cost. The total operational cost for Farm A was BBD 1,018.34 and for Farm B the total operational cost was BBD 1,935.12 (Table 2). The operational cost included the cost of the fish feed, fingerlings, water, electricity, seeding, labour and the iron chelate. The total initial capital cost for setting up the aquaponics farm was found to be BBD 62,000 for Farm A and BBD 40,000 for Farm B. These value were provided by the farmer owners based on the estimated amount that it cost them to set up the aquaponics. The exact breakdown of the cost was unavailable from Farm A however, since Farm B was recently constructed the cost breakdown of the BBD 40,000 was available and was as such:

- Aquaponic system (building and installation) – BBD 22,500
- Greenhouse – BBD 9,500
- Foundation - BBD 6,000
- Electrical plugs – BBD 2,000

The other materials and equipment required for both aquaponic systems were the fish tanks, sump, PVC pipes among other items (Table 1). These were some of the items required for both aquaponic farms.

Table 1 – Some of the items for the aquaponics system and the unit cost.

Item	Cost per unit (BBD)
Water pump	520.00
Air pump	330.00
Air blower	750.00
Fish tank	500.00
PVC pipe (ft) for the NFT	4.21

Based on the data from the farmers, it was found that for Farm A, the highest operational cost was the cost of the seedlings while for Farm B the highest cost was labour (Table 2). Seedlings cost made up 46 percent of the cost for Farm A and for Farm B labour made up 39 percent of the monthly operational cost. For both farms, the second highest cost was the electricity usage, which made up 24 percent of the total monthly cost for Farm A and 26 percent for Farm B. The lowest cost for the both farms was the water used accounting for 1 percent of the total operational costs compared to the other input items (Figure 3). The cost of water was low due to the water being used only to top up the system. Depending on how much water is lost, it determined how much water was needed to top up the system. However, it must be noted that during periods of rainfall, the two farms would be supplemented with rainfall to top up the system. For the month, Farm A used 0.5 m3 of water to top up the tank however, it was rounded to the nearest whole number which brought the volume of water used per month to 1 m3. Rounding off to the nearest whole number was also done for Farm B which brought the total volume of water used per month to approximately 3 m3 to top up the tank. It must be noted that the cost of water did not include the sewerage contribution and the garbage contribution which was implemented in 2018 after new policies were introduced by the new government after the elections in May 2018. The addition of these components will further increase the cost of the water bill.

Table 2 – Farm A and B's operational costs for one month.

Items	Farm A total operational cost (BBD)	Farm B total operational cost (BBD)
Fish feed	70.50	226.14
Fish fingerlings	120.00	100.00
Water	4.66	13.98
Electricity	242.89	500.00
Labour	0.00	750.00
Iron chelate	116.00	200.00
Seedlings (red and green lettuce – Farm A and red and oak leaf lettuce Farm B)	464.29	145.00
Total	**1,018.34**	**1,935.12**

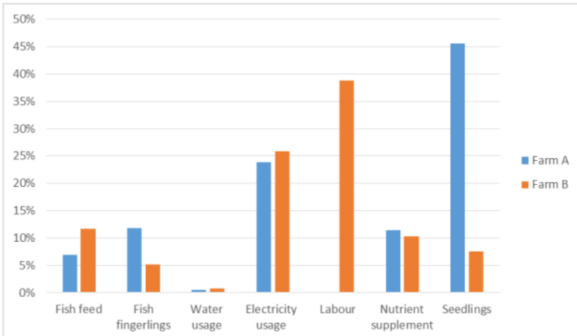

Figure 3 - The costs for Farm A and Farm B during one month

3.3. Estimated Revenue Generation

Due to Due to the challenges in obtaining the revenue gained from the two farmers, the revenue per month was estimated based on the number of holes contained within the aquaponic system, with lettuce being the main crop grown. The decision to use lettuce as the main crop was due to the farmers selling the lettuce per head and not per kg. At the time of the research, Farm A grew red and green leaf lettuce, chives, Chinese cabbage and kale. Therefore, for Farm A it was assumed that two types of lettuce (green and red leaf) would be sold. Farm B at the time sold red leaf, romaine and oak leaf lettuce, arugula, mint, chives, red mustard, swiss chard and basil and it was assumed that two types of lettuces (green leaf and oak leaf lettuces) would be grown.

For estimating the number of crops grown, Farm A's aquaponic system consisted of 3202 holes therefore, a total of 2,882 lettuces would be sold assuming that 10% of the crops grown is lost to pest damage. The farmer for Farm A charged BBD 2.00 per head of lettuce, therefore the estimated total revenue earned would be BBD 5764.00. With regards to Farm B, the system consisted of 1,000 holes and when the 10% crop loss was included the total crops sold would be 900. The farmer charged BBD 5.00 per head of lettuce therefore the total estimated revenue for the month would be BBD 4,500 for the lettuces. Additionally, Farm B sold the fish reared at BBD 15.40 per kg. During the time of the study, a total of 21.1 kg (after cleaned and gutted) of fish was harvested and a total of BBD 324.94 was made. This brought the total estimated revenue to BBD 4,824.94.

Table 3 – Estimated revenue earned for one month

Products	Farm A	Farm B
Lettuce	5,764.00	4500
Fish		324.94
Total	**5,764.00**	**4,825.56**
Profit	**4,745.66**	**2,890.44**

Both farms show that they are profitable with Farm A having a profit of BBD 4,745.66 and Farm B a profit of BBD 2,890.44 (Table 3). Farm A's profit came through the sale of the crops and for Farm B 93% of the profits came through the sale of the crops.

3.4. Cost Benefit Analysis

Following these results, a projection was made for the next 5-year period (Table 4). For each year the present value was calculated. Assuming that within the first year of operation, the cost would be higher than the revenue earned, the first year of the benefit cost analysis included the initial start-up cost and the operational cost per month. Based on the discussions with the farm owners it would take approximately six (6) months before a steady revenue can be earned and for the system to function fully. The discount rate used for calculating the present value was 8% based on the lending interest rate for Barbados from The World Bank collection of development indicators (Trading Economics 2018). From the present value calculated over the 5 years the payback period was calculated as well as the benefit cost ratio (BCR).

Table 4 – Benefit Cost Analysis for 5 years

Farms	Year 1 Present Value	Year 2 Present Value	Year 3 Present Value	Year 4 Present Value	Year 5 Present Value	Total
Operational Costs						
Farm A	$7,642	$8,503	$7,873	$7,290	$6,750	$100,058
Farm B	$11,501	$18,366	$17,005	$15,746	$14,579	$117,197
Revenue Generated						
Farm A	$44,522	$59,300	$54,908	$50,841	$47,075	$256,646
Farm B	$38,701	$47,971	$44,418	$41,127	$38,081	$210,302

The payback period for Farm A and B occurred in the second year of operation and the BCR calculated for the two farms was found to be 2.56 for Farm A and 1.79 for Farm B.

4. Discussion

Based on the results it was found that both farms were profitable and financially viable. Although the revenue generated was estimated, there was still a positive cashflow and most of that cashflow was due to the revenue generated by the sale of the lettuces. This information is useful for farmers in Barbados as it gives an indication of the kind of costs expected and the amount of revenue that can be generated. With regards to the operational cost, Farm B had higher costs than Farm A, this is due to Farm B paying more in fish feed, electricity and having to pay for labour.

Labour made up most of the cost for Farm B, which was 39% of the operational cost. This was similar to what was found in the study conducted by Bosma at al. 2017 where labour made up most of the cost. For Farm A, the highest cost was not labour but actually the cost of seedlings which contributed to 46% of the total operational cost. The cost of labour was not included in the operational cost for Farm A as the owner indicated that for the farm no labour is hired. The lowest operational cost for both farms was noticeably, the cost of water. This cost was low due to the price allocated to the volume of water used and to the system only requiring a small volume of water to top up the system. Since the water is recirculated through the system it reduced the volume of water added to top up the system. The water that is added, is only to replace the water lost through evaporation, evapotranspiration or spillage. It must be noted that most of the water used for aquaponics would be during the first start-up of the system, as such the cost of the water would be higher. It must be noted that the initial filling of the system would only be done once.

As identified in this study and in other literature, the initial start-up of aquaponics is the highest cost invested into aquaponics. To add to that the farmer would need consistent access to the inputs required to operate the aquaponics. For Farm B most of the start-up costs went into constructing and installing the aquaponics. Farmers would also need to consider that during the set-up of the aquaponics system, time is required for the system to build up the necessary beneficial bacteria needed to breakdown the nitrates from the fish feed and faeces to provide the plant nutrients. During the first year of operation, there will be negative cash flows, therefore a loss is expected. This is due to low revenue during the slow period in the first 6 months in operation.

Based on the results from the benefit cost analysis for the 5 years, aquaponics was still found to be financially viable. The BCR for both farms were over one (1) indicating that benefits (revenue) exceed the costs. This kind of finding can attract farmers towards adopting this aquaponic technology since the benefit cost analysis for both farms regardless of the size differences and costs involved were able to have a financially viable system.

Additionally, the payback period for both of these systems was within two years which was similar to what was recorded in the literature. Though the focus was only placed on the lettuce there were other crops which can further increase the profitability of the aquaponics. However, this profitability would be dependent on the market. Since the revenue was estimated based on per head of lettuce sold, higher profits can be gained by selling the crops per kg. What was also noticed was that most of the profits were gained from selling the crops than from the fish in the case of farm B. There are other means by which additional profits can be gained, and this can be through tours to the aquaponic farms and consulting services in setting up the aquaponic systems for customers.

5. Conclusion

The two farms were found to be financially viable despite their size. The economic returns for both farms were evident. Most profits were gained from the selling of the crops and depending on the type of crop needed for the market. The highest costs required for aquaponic systems was during the initial set up in the construction of the aquaponic system. During the operational stages, labour was one of the highest costs. The other costs involved in the operation of aquaponics include electricity, fish feed, water, seedlings among others. The payback period for both farms was short as within two years farmers would get back what they would have invested.

By studying actual farms within Barbados, it provides a better representation and understanding of the possible costs and revenue that can be gained through aquaponics. It will further aid farmers in making decisions on whether they should go ahead with growing crops using this technology.

Although this study had some limitations in obtaining the actual revenue gained from the sale of the crops and with some costs not being included, further work should be done in analyzing the viability of aquaponics but for over a longer period. Furthermore, research should be done in comparing the conventional agriculture with aquaponics to determine which option is more viable and profitable. Also, a market analysis should be carried out on existing aquaponic farms.

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